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Surface Properties of AA7075 Aluminium Alloy Shot Peened under Different Peening Parameters

E. AVCU[a,b]

[a] Kocaeli University, Ford Otosan İhsaniye Automotive Professional School, Department of Machine and Metal Technologies, 41680, Kocaeli, Turkey
[b] Kocaeli University, Surface Treatment Laboratory, 41680, Kocaeli, Turkey

Abstract:
AA7075 aluminium alloy was shot peened with different size stainless steel shots at different peening pressures while focusing on investigating the surface properties of AA7075 alloy such as surface morphology, topography, and roughness. Since shot peening (SP) is an important mechanical surface treatment which leads to the local plastic deformation in the surface and sub-surface regions and eventually affects surface properties, the present study aims to clarify the effects of SP parameters on the surface properties of AA7075 T6 alloy. A custom-design SP system was used to shot peen the alloy by stainless steel shots with size of 0.1-0.3 mm and 0.4-0.9 mm at peening pressures of 2 bar and 4 bar. The surface properties depending on shot size and peening pressure were investigated by a scanning electron microscope (SEM) equipped with energy dispersive X-Ray spectroscopy (EDX) and a 3D optical profilometer. The surface morphology affected by both parameters; larger shots and higher pressures caused higher plastic deformation, which led to the formation of more complex and rough surfaces in comparison to the surfaces shot peened with smaller shots at lower pressures. 3D surface topographies were visualized the deformation, which revealed the effects of shot size and pressure. The surface roughness increased with increases in both particles size and pressure, which caused highly deformed and rough surface topographies with a great number of dimples. Embedding of fragmented shot particles occurred during peening.
Keywords: AA7075 Alloy - Shot Peening - Shot Size - Peening Pressure - Topography.
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1. Introduction

Shot peening (SP) is a mechanical surface treatment which hardens metal surfaces by means of cold deformation [1-5]. SP has been widely utilised in various industrial applications [2,3,6,7] to improve the fatigue life of materials [2,4,7-11] by the repeated high velocity impacts of shots onto the surfaces [2,4,10], in which the surface roughness [3] and surface hardness [5] are changed. The surface and sub-surface modifications induced via SP can be summarised as; i) compressive residual stress occurs owing to the formation of plastic deformation [4,12] and localised micro-strain [2,6-8,11,13,14], ii) work hardening occurs due to the increases in dislocation density and decreases in grain size [3-6]. These modifications can be considered as the beneficial consequences of SP while surface properties such as surface roughness increases due to SP [2-4] which may accelerate crack nucleation and may detrimentally affect fatigue life [4]. The formation of new cracks due to the increased surface roughness caused by SP has been reported in the literature [8,10]. Moreover, it has been reported that the corrosion resistance of materials decreases [5] due to the increased surface roughness caused by SP. Therefore the effects of SP on the surface properties of materials have to be carefully controlled by adjusting SP parameters such as shot type, peening pressure (impact velocity), and peening duration [4].

Aluminium (Al) alloys are highly demanded in industries where weight reduction is necessary due to the need for reducing fuel consumption and increased environmental awareness [15]. High strength Al alloys, especially 7xxx series, are being increasingly used in the fabrication of structural components in aerospace, automotive, and marine industries owing to their excellent specific strength, low cost, good machinability, excellent toughness, and fatigue resistance [16-25]. Commercial AA7075

Corresponding Author E-mail: avcuegemen@gmail.com

alloy consists of 5-6 wt% Zn, 2-3 wt% Mg and 1-2 wt% Cu and possesses a typical yield strength of 490 MPa and a ultimate tensile strength of 570 MPa with an applied standard T6 precipitation hardening heat treatment [19]. However, higher mechanical properties such as surface hardness and fatigue strength have been demanded for AA7075 alloy to extend their usage and lifetime, which could be simply achieved by modification of the microstructure [21,25]. SP can be considered as one of the tremendous methods to modify the microstructure of AA7075 alloy by increasing grain refinement and dislocation density of surface and subsurface [1,26], thus SP has been widely applied to enhance the mechanical properties of Al alloys during the past decades [14,26-29].

Zupanc and Grum [30] reported that SP positively affects the fatigue life of AA7075 alloy due to the formation of compressive residual stress while the increase of surface roughness could cause formation of fatigue cracks. Trsko et al. [9] presented the fatigue life of AW7075 alloy after severe SP with different intensities and concluded that work hardening by SP increases the fatigue strength under optimum intensities while excessive SP intensity leads to the decrease of fatigue strength. Oguri [29] investigated the fatigue life AA7075-T6 alloy by fine particle shot peening (FPSP) and concluded that the fatigue life enhancement could be increased more with FPSP than SP owing to the formation of fine dimples with low surface roughness and high compressive residual stress by FPSP. More studies have been published focusing on the effects of SP and SP parameters on the mechanical properties of aluminium alloys such as 2124-T851 [28] and 5056 [27]. Most of the literature studies have mainly focused on the fatigue life enhancement by SP while the effects of SP parameters on the surface properties of AA7075 alloy have not been comprehensively clarified yet. The present study investigates the effects of shot size and peening pressure on the surface morphology, 3D topography, and surface roughness values of AA7075 alloy in detail.

2. Materials and Methods

2.1. Materials:

In the present study AA7075 T6 alloy was used, which was supplied as 25 mm diameter rod material. The specimens were prepared by cutting rod material via a precision cutting machine (Microcut 151, Metkon Instruments Inc., TR), eventually AA7075 T6 specimens with a diameter of 25 mm and with a length of 10 mm were obtained. The chemical composition and mechanical properties of AA7075 T6 alloy are summarised in Table 1.

Table 1. Mechanical properties and chemical composition of AA7075 alloy.

Chemical composition					
Elements	Zn	Mg	Cu	Fe	Si
wt%	5.60	2.5	0.21	0.21	0.14
Mechanical properties					
	Hardness Vickers	Tensile Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation at break (%)	Elasticity Modulus (GPa)
	175	503	570	11	71

SP was carried out by using 0.1-0.3 mm (trading name Chronital S10) and 0.4-0.9 mm (trading name Chronital S60) sizes stainless steel shots, which were supplied from Fetaş Blasting Company, Turkey. The chemical composition of the shots is given in Table 2.

Table 2. Chemical composition of stainless shots.

Elements	C	Cr	Ni	Mn	Si	S	P
wt%	0.10-0.13	18.0-19.0	8.0-10.0	<2.0	<3.0	<0.03	<0.04

2.2. Methods:

The specimens were metallographically prepared prior to SP. They were grinded with 120, 320, 600, and 1000 mesh grits and were polished with a diamond solutions of 1 and 6 microns by using a grinding and polishing machine (Forcipol 1V, Metkon Instruments Inc., TR). The surfaces of the specimens were cleaned with alcohol and dried in hot air.

Shot peening was performed by using a custom-designed shot peening rig which allows shot peening under various parameters such as peening distance, peening angle, shot size, and peening pressure. The SP system consists of an air compressor, a dehumidifier, a pressure regulator, a blasting cabinet and other related pneumatic equipment such as valves and pipes. In this study, SP were applied on AA7075 T6 specimens by using two different size stainless steel shots at two different peening pressures. Furthermore, the Almen intensities under these parameters were measured by using A strip Almen strips. The SP parameters implemented during the present study are schematically illustrated in Figure 1 and given in Table 3.

Corresponding Author E-mail: avcuegemen@gmail.com

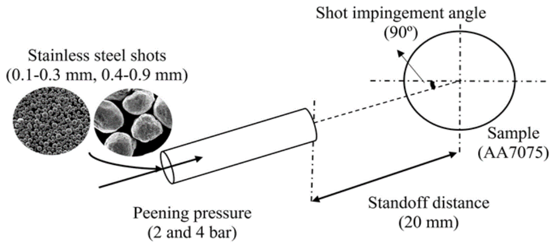

Figure 1. Schematic illustration of SP methodology.

Table 3. Shot peening parameters and measured Almen intensities.

Diameter of nozzle (mm)	Length of nozzle (mm)	Test temperature (°C)	Shot type	Shot diameter (mm)	Peening pressure (bar)	Peening duration (s)	Coverage (%)	Almen intensity (mmA)
7.5	130	25	Stainless steel shots	0.1-0.3	2	60	100	0.08
				0.1-0.3	4			0.16
				0.4-0.9	2			0.32
				0.4-0.9	4			0.70

The 3D surface topographies were analysed via an optical profilometer (Nanovea ST400 Profilometer, USA). The surface roughness values of the speciemens peened under different parameters were analysed in accordince with ISO 25178-2012 standarts [31]. Briefly, an area of 4×4 mm from the shot peened surfaces of the specimens were scanned with a non-contact profilometer, afterwards, the 3D surface topographies and areal surface roughness values of the specimens were analysed by using a surface analysis software (MountainsMap® Premium software, FR). The schmeatic illustration and the parameters of the surface analyses applied on the specimens representing real surface, topographical view, 3D surface topography and surface roughness parameters are given in Figure 2.

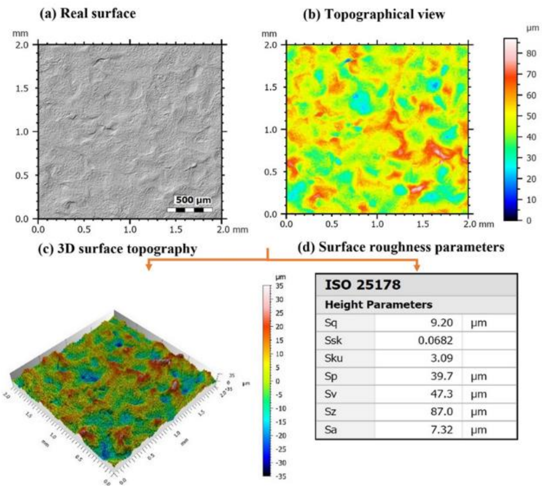

Figure 2. Schematic illustration of the applied surface analyses representing; (a) real surface, (b) topographical view, (c) 3D surface topography, and (d) surface roughness parameters.

Furthermore, the surface morphology of the specimens after SP were examined by a scanning electron microscope (SEM) equipped with a enegy distribution spectrometer (EDS) (Bruker Quantax EDS brand).

3. Results and Discussion

SP alters surface topography and increases surface roughness due to the repeated impact of shots [2,28,32] which may detrimentally affect the fatigue strength of shot peened materials probably due to the early crack nucleation [1,33,34]. The increase of roughness occurs due to SP [33,34] which may decrease the corrosion resistance due to increases in the surface area subjected to corrosive environment and high ion release rate [1,32,34]. Therefore, it is important to investigate the effects of SP on the surface topography and roughness. The surface topography of the aluminium alloy significantly affected by SP [1,10,33] as valleys and peaks were formed on the surfaces by the impact of stainless steel shots specifically at higher peening pressures as seen in Figure 3 (b) and (d). The roughness of the specimens increased with increases in peening pressure as expected due to the high collision energy of shots [3,27,32,35] (Figure 4). The obtained areal surface roughness values of the specimens peened with large shots at high pressures were significantly higher than that of the existed literature studies [10] which could cause significant reduction in fatigue life (Figure 4).

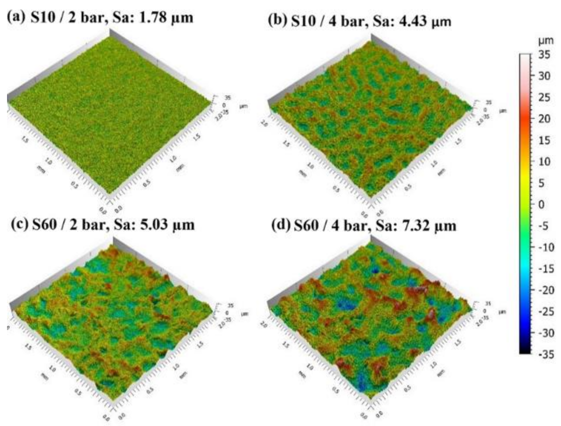

Figure 3. 3D surface topographies of the specimens shot peened under different parameters; (a) at 2 bar with S10 shots, (b) at 4 bar with S10 shots, (c) at 2 bar with S60 shots, and (d) with 4 bar with S60 shots.

It was shown that the improvement of the fatigue strength of AA7075 T6 aluminium alloy could be lowered by the rough surface topography formed by SP [10]. Therefore, the SP parameters should be carefully controlled and optimised [36] or

Corresponding Author E-mail: avcuegemen@gmail.com

a surface treatment such as tribofinishing should be applied to reduce the surface roughness after SP [10]. SP caused the formation of large and deep dimples at higher peening pressure which caused asperities on the surfaces and the value of peak to valley was measured as around 70 µm for the specimen peened with S60 shots at 4 bar peening pressure as given in Figure 3 (d). The increase of peening pressure increased the Almen intensity (Table 3) and caused rougher surface [1] due to the severe plastic deformation of the AA7075 alloy which was well correlated with the given 3D surface topographies (Figure 3). The increase of shot size caused the formation of larger and deeper dimples than that of smaller shots, thus led to a rough surface topography with a great number of asperities (Figure 3 (c) and (d)). The average roughness (S_a) values, the maximum heights of peaks (S_p), and valleys (S_v) increased with the increases in shot size as seen in Figure 4. It was stated that the plastic strain caused by the shots increases with increasing size of shots owing to the increased kinetic energy [37]. Furthermore, shot size may affect the homogeneity of the surface during SP and increasing shot size could increase the homogeneity of surface [32]. The surfaces peened with two different size shots at 2 and 4 bar pressures exhibited a uniform surface as seen in Figure 3.

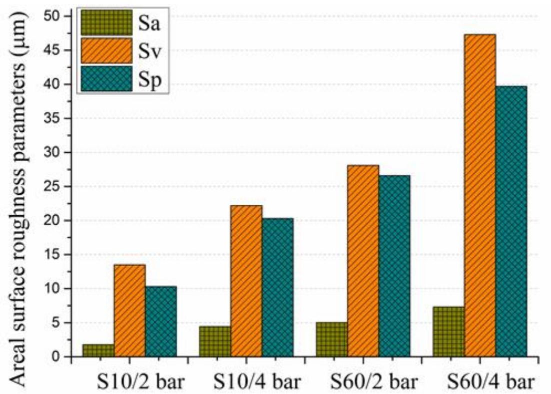

Figure 4. Areal surface roughness parameters of the shot peened specimens.

In the present study the surface roughness increased with increases in both peening pressure and shot size which could be attributed to the increase of Almen intensity due to the variation of these parameters (Table 3) and probably due to the severe plastic deformation and high plastic strain [37]. However, it was also reported that increasing shot size could lead to a lower surface roughness at a constant Almen intensity [32]. Beside the shot size many other factors such as Almen intensity, shot velocity [38], and coverage [39,40] may also affect the plastic strain and the resultant surface roughness of peened surface, thus the effects of these factors should be considered to evaluate the effect of shot size on the surface properties.

The surface morphologies of peened surfaces were discussed to understand the effect of shot size and peening pressure on the surface properties of AA7075 alloy (Figure 5 and Figure 6). The dimples observed on the surfaces peened at 4 bar peening pressure with S10 and S60 as shown in Figure 5 (c) and Figure 6 (c) which were formed due to the plastic deformation formed by the impact of shots during SP [38,39,41] while smaller dimples were formed at low peening pressures due to the lower kinetic energy of shots at relatively lower pressures [42], an example as shown in Figure 6 (a).

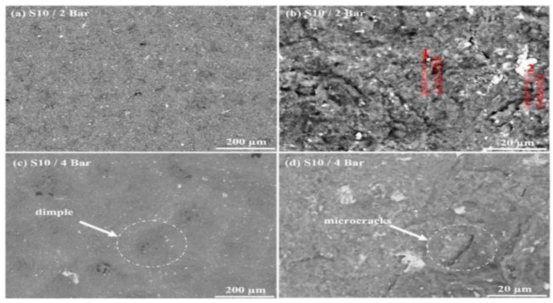

Figure 5. Surface morphologies of the specimens shot peened with S10 shots (0.1-0.3 mm); (a) and (b) at 2 bar, (c) and (d) at 4 bar.

Ahmed et. al [32] reported that decreasing shot size decreases the size of dimples formed during SP. In the present study, the size and depth of the dimples were significantly increased with increasing shot size and peening pressure as seen in Figure 6. The increased size and depth of the dimples could be the underlying reasons of the increase of surface roughness and the variation of surface topography as discussed previously (Figure 3 and Figure 4). Apart from the micro dimples formed with SP [2], surface microcracks occurred due to the impact of shots during SP which corresponds to the un-desired surface damages [40]. The formation of microcracks were visible even on the surfaces peened at 4 bar with S10 shots as seen in Figure 5 (d) while larger cracks observed for the surfaces peened with S60 shots at peening pressures of 2 and 4 bar presented in Figure 6 (b) and (d). Therefore, it is concluded that micro cracks could be formed at relatively higher pressures due to the excessive plastic deformation of the surfaces caused by the high kinetic energy of shots [39] which may also cause the increase of surface roughness. The increase of surface cracks formation on the shot peened surfaces could be attributed to the increase of plastic deformation at relatively higher Almen intensities (Table 3), which could reduce the

Corresponding Author E-mail: avcuegemen@gmail.com

beneficial effects of SP on fatigue life.

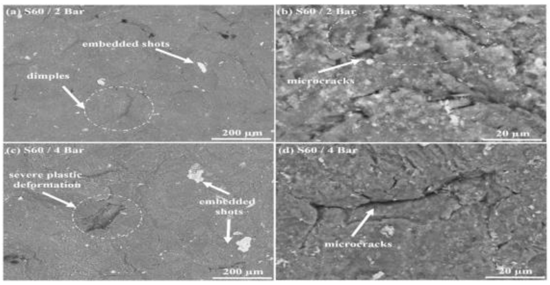

Figure 6. Surface morphologies of the specimens shot peened with S60 shots (0.3-0.9 mm); (a) and (b) at 2 bar, (c) and (d) at 4 bar.

The white coloured regions seen in the surface morphologies of the peened specimens were determined as the embedded stainless steel shot fragments as shown in Figure 6 (c) while the remaining light grey coloured regions represented the aluminium matrix as confirmed by EDS analysis (Table 4). The shot media could be fragmented into smaller and sharp particles due to the collision of incoming and rebounding shots during SP [4] and these newly formed particles may be penetrated into the surface of material with the impact of following shots. The surface of aluminium alloy is relatively ductile in comparison to the stainless steel shots which could lead to the embedding of these newly formed sharp fragments of shots onto the surface with ease. The embedding of fragments onto the aluminium surface could detrimentally affect fatigue behaviour by acting as early crack nucleation sites [4].

Table 4. EDS spectrums of the shot peened surface.

Elements wt%	Al	Mn	Cr	Si	Fe	Zn	Mg	O	C
Spectrum 1	30.2	7.7	6.2	4.9	3.5	2.2	1.6	23.2	20.6
Spectrum 2	-	6.6	14.8	5.8	47.9	2.0	-	7.8	-

4. Conclusions

This paper investigates the effects of shot size and peening pressure on the surface topography, roughness, and morphology of AA7075 T6 aluminium alloy. The major conclusions and the future studies are summarised in this section.

The variation of surface topography dependent on shot peening parameters were visualised by 3D surface topographies and clarified with areal surface roughness parameters. The surface properties of AA7075 alloy were significantly affected by both peening pressure and shot size. Larger shots and higher pressures led to a higher plastic deformation, which caused a relatively more complex and rough surface topography than that of surfaces shot peened with smaller shots at lower pressures. Formation of dimples was identified through SEM analysis, which indicated the effects of shot size and peening pressure on the surface morphology and eventually represented the underlying reasons of the variation of surface roughness.

Embedding of fragmented shot particles during SP were highlighted via SEM with EDS analysis.

Although most of the literature studies have examined the variation of residual stress during SP dependent on the Almen intensity, further studies are recommended to directly investigate the effect of peening pressure and shot size on the residual stress of aluminium alloys. Moreover, the effects of these parameters on the wettability of peened surface and adhesion strength between shot peened material and various coatings would be also investigated as future studies.

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Corresponding Author E-mail: avcuegemen@gmail.com